Design of Electromagnetic Relay

The Plunger

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Abstract

Relays are used industrially in a wide variety of applications. Traditional mechanical relays are large, slow, noisy devices, but are still widely used in various machines and processes for control purposes. In this paper cross section of a moving electromagnetic relay is A; can be inside the external vertical hole magnetic chamber. Gap between the two is negligible. r is the resistance in ohms, and the coil has N turns. Once a potential source v volt DC and again, AC power is applied to the ends of the coil. Magnetic material can be assumed to be ideal up to saturation flux density of 1.6T. Regardless of efflorescence flux in the air gap. The force exerted on the moving parts is computed as a function of the air gap y. Next, effect of the dynamic equations is also checked.

Keywords

Electromagnetic Relay; Plunger; Finite Element Methods

Introduction

Two key factors in selecting an actuation mechanism are reliability and cost. In terms of reliability, eelectromagnetic actuators can be controlled with low-cost electronics. In terms of reliability, relay design requires the creation of executable models for both features, the elastic spring and the tension generated by electromagnets during the performance measure the relative energies associated with both, displacement coil and magnetic attraction for each component, Than another, provides a range of design. Solving nonlinear ordinary differential equations with two couples Accurately simulates the dynamic response characteristics of the instrument. Here, less is studied to the elastic spring. And more, the electromagnetic equations, force calculation, and then examines the dynamic equations.

The studies done on this field including: (1) Inductance of a plunger-type magnet: In this paper, a method for the evaluation of this function, using Mathcad, is proposed and two verifications of the formula are performed: using a finite element method and experimental determinations of the total inductance for large range of the gap variation. The experimental values are compared with the sum of internal inductance, calculated with formula and external inductance calculated with finite element method [Cividjian et al. (1998)]. (2) In second paper: Equations derived from the continuum design sensitivity analysis (CDSA), in conjunction with the material derivatives for a continuous medium and using the energy-based approach, have been successfully applied to the calculation of both total force and force distributions. The resultant expressions are similar to the Maxwell Stress Tensor, Magnetic Charge method, and Virtual Work Method but have several advantages over the traditional approaches. Numerical implementation of the scheme leads to efficient calculations and improved accuracy [Kim et al. (2007)]. (3) The third paper: It present a novel moving-iron, high-pressure, high-speed electromagnetic actuator that utilizes permanent -magnet (PM) shielding for increasing air-gap flux. We analyze its static and dynamic characteristics by using the finite-element method, taking into account the nonlinear characteristics and the eddy-current loss of the magnetic material. The experimental and simulated results agree well and show that the actuator has a displacement of 0.6 mm, closing time of 2.24 ms, and opening time of 7.78 ms without latching force [Man et al. (2010)]. Therefore, in this paper, tried that, Precautions be followed.

Calculations of the Electromagnetic Force

The mechanical attractive force generated by passing current through a solenoid can be determined using

Ampere and Faraday's laws of magnetism. Ampere's law stipulates that the integration of magnetic field intensity, H, around a closed contour of length l is equal to the net current crossing the surface of the closed contour:

$$\oint \vec{H}.d\vec{l} = Ni \tag{1}$$

where i is the applied current and N is the number of times the current encircles the contour. The integral of the field intensity in the contour is equal to the total magnetic flux, φ, divided by the cross sectional area, A, and the magnetic permeability, μ, of the material:

$$H = \frac{\varphi}{\mu A} \tag{2}$$

$$\oint \frac{\varphi}{\mu A}.d\vec{l} = Ni \tag{3}$$

where the flux can be separated from the integral by defining a term for the magnetic resistance called the reluctance, R. Ampere's law can then be rewritten in terms of the magnetic flux and resistance through a material as:

$$R\varphi = Ni \tag{4}$$

The reluctance of air gap:

$$R = \frac{x_{gap} - x}{\mu A} \tag{5}$$

The reluctance of the air gap with permeability, μ 0, is defined by the displacement of the spring, x, from its initial gap distance, x_{gap}. Ampere's law was developed for time invariant fields. Thus when considering only Ampere's law, x=0 and the reluctance remains constant.

TABLE I PHYSICAL CONSTANTS FOR ELECTROMAGNET DESIGN

Physical constants	***value***
Applied Current (A)	3
Number of Turns (N)	100
Permeability of Free Space (μ_0)	$4\pi \times 10^{-7}\ N/A^2$
Permeability of Nickel (μ)	$800 \times \mu_0$
Area cross plunger(m2)	3.8×10^{-4}
Initial air gap(mm)	0.5

The flux linkage is defined as the number of turns in the coil multiplied by the magnetic flux passing through the cross-sectional area of the coil. The voltage may then be derived as:

$$V = \frac{d(N\varphi)}{dt} = \frac{\partial(N\varphi)}{di}\frac{di}{dt} + \frac{\partial(N\varphi)}{dx}\frac{dx}{dt} \tag{6}$$

Equation (6) can be rewritten using the inductance, L, of the circuit times the current, and the speedance, Ks, of the circuit times the velocity of the plunger:

$$V = L(x,i).\frac{di}{dt} + K_s(x,i).\frac{dx}{dt} \tag{7}$$

The speedance is the coefficient of motional EMF across the coil and can be derived as:

$$K_s(x,i) = N\frac{d\varphi(x,i)}{dx} = N\frac{d}{dx}\left(\frac{Ni}{R_g}\right) \tag{8}$$

Assuming no electrical power loss in the coil, the change in work done as the total flux changes is:

$$W = \int i.d(N\varphi) = \int R\varphi.d\varphi = \frac{1}{2}iN\varphi \tag{9}$$

The force acting on the second magnetic element is:

$$F = -\frac{dW}{dx} = -\frac{Ni}{2}\frac{d\varphi}{dx} \tag{10}$$

Substituting for the reluctance in the solution of the magnetic flux, the force provided by the electromagnet on the magnetic plunger can be written as:

$$F_{mag} = \frac{(Ni)^2}{2\mu_0 A}\frac{1}{\left[\frac{x_{gap} - x}{\mu_0 A}\right]^2} \tag{11}$$

The Exact Dimensions of the Model

Dimensions of the simulation model in the software Maxwell Presented as follows:

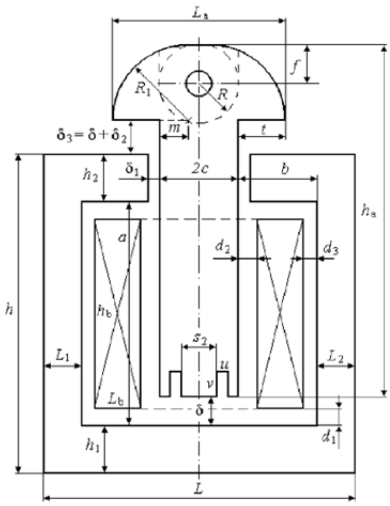

FIG. 1 PLUNGER MODEL

TABLE II DIMENSIONS OF THE SIMULATED MODEL

Var.	***mm***	***Var.***	***mm***	***Var.***	***Mm***
a	40	u	2.5	R	10
c	9.5	v	2.5	a'	40
b	10.5	L_t	9	h_b	39
d_1	0.5	δ_1	0.5	h_1	10
D_2	0.5	δ_2	0.5	h_2	10
d_3	0.5	h_4	60.5	t	4.8
h	60	L_1	10		
L	60	L_2	10		

Analysis and Simulation

In this section plunger simulated by two state.

Sinusoidal Voltage

For example, we have applied sinusoidal voltage $V(t)=100\sqrt{2}\cos(120\pi t)$. displacement to 1mm we calculate amount of force applied to the piston, Current is:

$$i(t)=\frac{V(t)}{z}=\frac{100\sqrt{2}\cos 120\pi t}{\sqrt{r^2+(L\omega)^2}}$$

$$L\omega=\frac{N^2\mu_0 A\omega}{2x}=\frac{100^2\times 4\pi\times 10^{-7}\times 380\times 10^{-6}\times 120\pi}{1\times 10^{-3}}=1.80$$

$$i(t)=\frac{100\sqrt{2}\cos 120\pi t}{\sqrt{4^2+(1.8)^2}}=\frac{100\sqrt{2}}{4.39}\cos 120\pi t$$

$$f=\frac{1}{2}\left(\frac{100\sqrt{2}\cos 120\pi t}{4.39}\right)^2\times\ldots$$

$$\frac{100^2\times 4\pi\times 10^{-7}\times 3.8\times 10^{-4}}{2}\left(-\frac{1}{10^{-6}}\right)$$

$$f=-1238\cdot 89\cos^2 120\pi t=-1238\cdot 89\left(\frac{1+\cos 240\pi t}{2}\right)$$

$$\rightarrow f_{av}=619\cdot 445N$$

In the figure 2, Displacement one mm moving parts is shown.

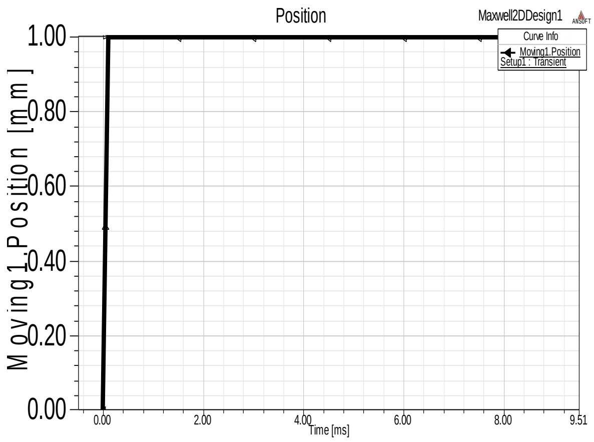

FIG. 2 DISPLACEMENT ONE MM MOVING PARTS

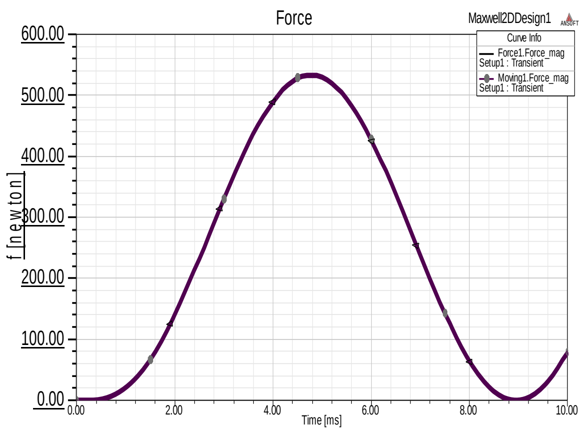

FIG. 3 ELECTROMAGNETIC FORCE, FOR A SINUSOIDAL VOLTAGE $V(t)=100\sqrt{2}\cos(120\pi t)$

In the figure 3, the peak power is 532.8N with the calculated value 619.44N is about 14% difference. This large variation due to the reluctance of the fixed and removable nozzle gap is negligible. So it is better to be considered. Positive sign, because it is also the size of the force, the plot here.

In the figure 4, peak current is In the shape about 34.27A. With calculated amount 32.21A, a difference of about 6%.

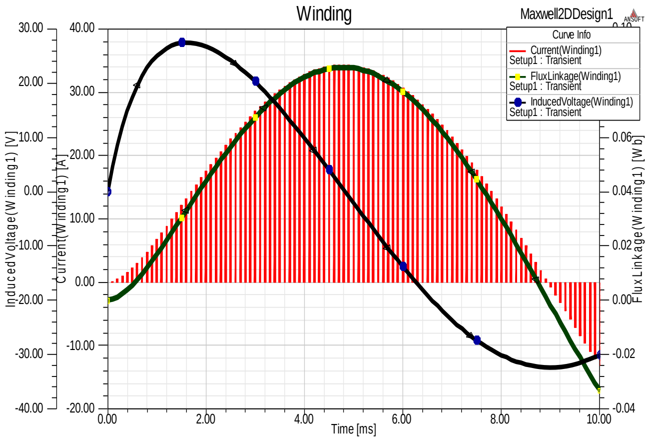

FIG. 4 THE RED IS CURRENT

DC Voltage

For a voltage V_{DC}=12V, and the flux density of 1.6T assuming that the magnetic material is ideal. To calculate the amount of force to Displacement 1mm, Current steady state is as follows:

$$i=\frac{V}{r}=\frac{12}{4}=3A$$

$$\varphi=BA=1.6\times 3.8\times 10^{-4}=6.08\times 10^{-4}\,wb$$

$$R=\frac{F}{\varphi}=\frac{Ni}{\varphi}=\frac{100\times 3}{6.08\times 10^{-4}}=.0439\times 10^6\rightarrow L=\frac{N^2}{R}=0.228H$$

$$y=R\mu_0 A=.0439\times 10^6\times 4\pi\times 10^{-7}\times 3.8\times 10^{-4}$$

$$=2.1\times 10^{-5}=0.021mm$$

$$f=\frac{1}{2}(3^2)\left(-\frac{100^2\times 4\pi\times 10^{-7}\times 3.8\times 10^{-4}}{10^{-6}}\right)=-21.488N$$

This means that that for every y <.021 mm, the force exerted on the piston due to the saturation of magnetic material, is fixed. The gap is greater, R is greater reluctance, L is less inductance, B is less; then magnetic material is not saturated. And vice versa.

Figure 5 compares the calculated value of the force difference is the difference between taking the spring constant K occur in software.

We see in Figure 6, the peak current is 3A. And is accordance with calculated value.

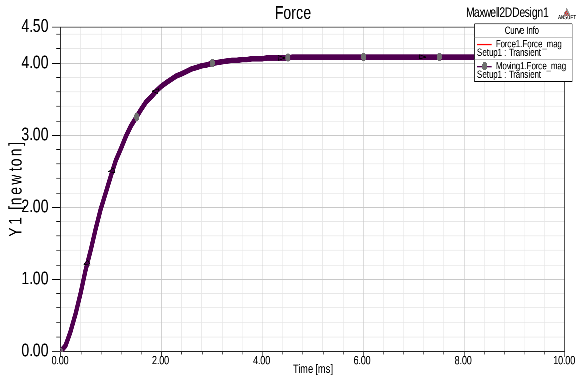

FIG. 5 FORCE TO PISTON

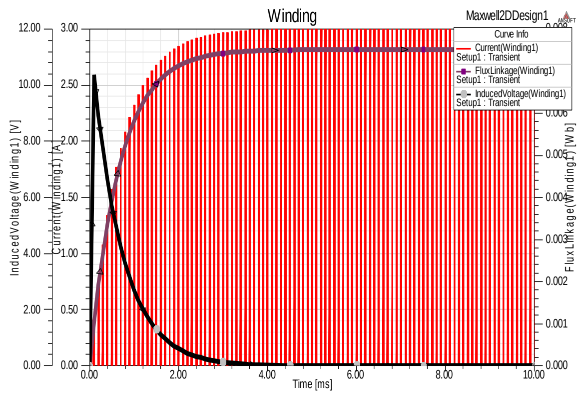

FIG. 6 THE RED COLOR REPRESENTS THE CURRENT

Dynamic Equations

Using equations previously described, Coupled set of first order nonlinear differential equations can be developed to make a completely model tool.

$$\frac{dx}{dt} = v$$
$$m.\frac{dv}{dt} = F_g - K.x - b(x,i).v + K_s(x,i).i \qquad (12)$$
$$L(x,i).\frac{di}{dt} = V_a - K_s(x,i).v - R..i$$

Which, b is the damping coefficient of viscosity, and K is mechanical spring constant.

$$b = \frac{3.v'.A^2}{2.\pi.(x_{gap} - x)^3} \qquad \textbf{(13)}$$

Which, $v' = 1.583\times10^{-5} kg/(m.s)$, $A = 3.8\times10^{-4} m^2$ then $b = 2.872 N.s/m$.

Inserting values with $K_s = .2$, $K = 5335$, $L = .228$, $V_a =$ $12vDC$, $m = .009kg$, $F_g = 0.09N$ and writing equations in the form of state equations and solve it in software obtains the required waveforms.

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = \frac{1}{.009}(0.09 - 5335.x_1 - 2.87.x_2 + 0.2.x_3) \qquad \textbf{(14)}$$
$$\dot{x}_3 = \frac{1}{0.228}(12 - 0.2.x_2 - 4.x_3)$$

These three equations are solved in MATLAB using the solver ODE45.

In the figure 7, after connecting the power piston may fluctuate. And in the end proved to be the .1 mm, But the position is not zero.

In the figure 8, the piston is fixed and have no speed.

In the figure 9, Current, according to calculations at steady state, is fixed to the 3A.

But, with a alternating source Position changed oscillatory. Due to the structure Plunger, here is unacceptable. But it can be use in a tool as a Moser machine that is as small fluctuations, but the two sides are allowed to fluctuations reciprocating this AC voltage is applied. Note to Figures 8 to 10. Of course, in theory, be made condition on the position that never becomes negative but this condition also affects the other two state variables.

In the figure 11, at the moment, connect the source; in piston speed, several peak occurs. This is not too far from expectation.

The coefficients of the equations were estimated. To achieve more accurate response parameter should be calculated as the exact Ks. Formalin calculate parameter such as b, also are approximate. Other state variables like the electromagnetic force, energy field or flux linkage can be added into the state equation. But we could directly use Rung-kuta format to solve the equations. Again, this method is based on ODE45.

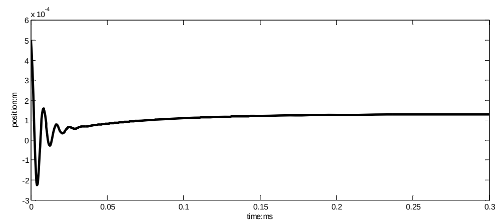

FIG. 7 PISTON POSITION CHANGES

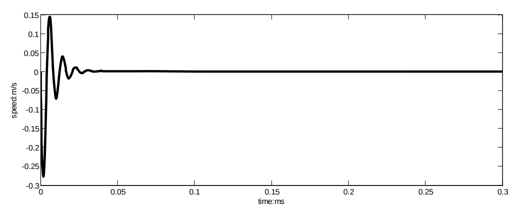

FIG. 8 PISTON SPEED CHANGES

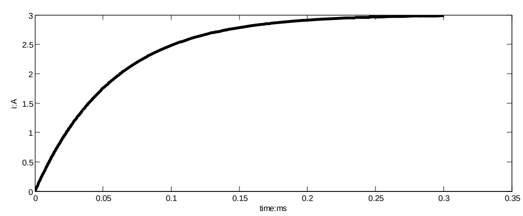

FIG. 9 CURRENT IN THE COIL

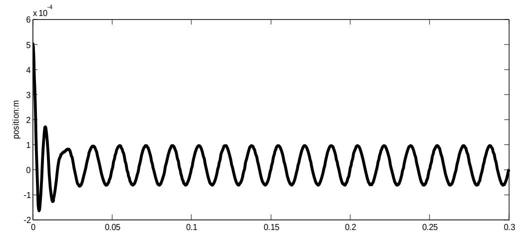

FIG. 10 PISTON POSITION CHANGES

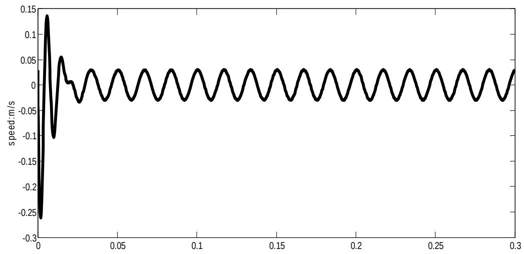

FIG. 11 PISTON SPEED CHANGES

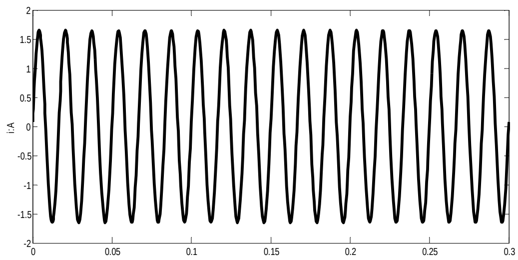

FIG. 12 CURRENT IN THE COIL

Conclusions

Seen, the calculated values and simulation values were somewhat close together, If, in the calculation, regardless of the approximation, the accuracy is higher. But the possibility of lack of convergence, also not unexpected the correct answer in Maxwell Software. In the analysis of the dynamical equations we assumed constant the L and R. Ideally, of course, will mean that B=1.6T. But in the General state changes of R and L, also changes the equation. The current form will have minor changes in the transient state. Dependence of dynamic and the electromagnetic equations causes to solve the range of problem and design.

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REFERENCES

Cathey, Jimmie J., "Electriacal Machines Analysis And Design Appling MATLAB," McGraw-Hill, Vol. 2001.

Cividjian, G. A. et al., ''Inductance of a plunger-type magnet'', IEEE Trans. on Magnetics, vol. 34, no. 5, Sept. 1998, pp. 3695-3688.

Dolan, Alin-Iulian, "Contributions to modeling of the fields and of the transient regimes in electrical equipments," Abstract Of Phd Thesis, University Of Craiova , Craiova, 2009.

Hunt, Brian R., "*Differential Equations With MATLAB,* " *JOHN WILEY & SONS INC, 2005*.

Kim, Dong-Hun, Lowther, David A., and Sykulski, Jan K., '' Efficient Global and Local Force Calculations Based on Continuum Sensitivity Analysis'', IEEE TRANSACTIONS ON MAGNETICS, VOL. 43, NO. 4, APRIL 2007.

Krause, Paul C., Wasynczuk, Oleg, Sudhoff, Scott D., "Analysis of Electric Machinery and drive Systems, " 2th Edition, *JOHN WILEY & SONS INC*, 2002.

Man, Jun, Ding, Fan, Li, Qipeng, and Da, Jing, '' Novel High-Speed Electromagnetic Actuator With Permanent-Magnet Shielding for High-Pressure Applications', IEEE TRANSACTIONS ON MAGNETICS, VOL. 46, NO. 12, DECEMBER 2010.